Global Calibration of the GEOS-5 L-band Microwave Radiative Transfer Model over Land Using SMOS Observations

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Outline

Soil Moisture and Microwave Radiances

Calibration

Brightness Temperatures

RTM Parameters

Remaining Biases

Conclusions

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Soil Moisture and Microwave Radiances

Brightness Temperature (Tb)

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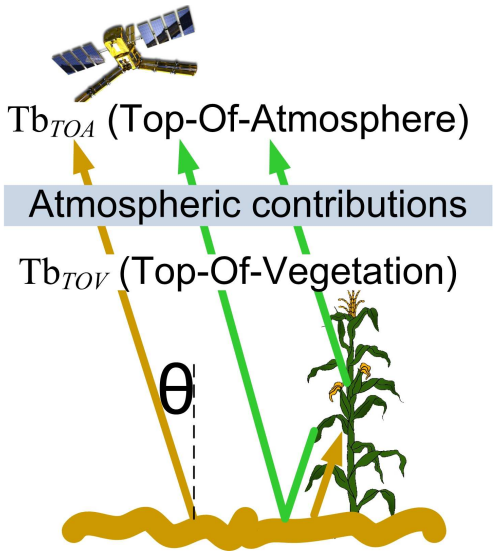
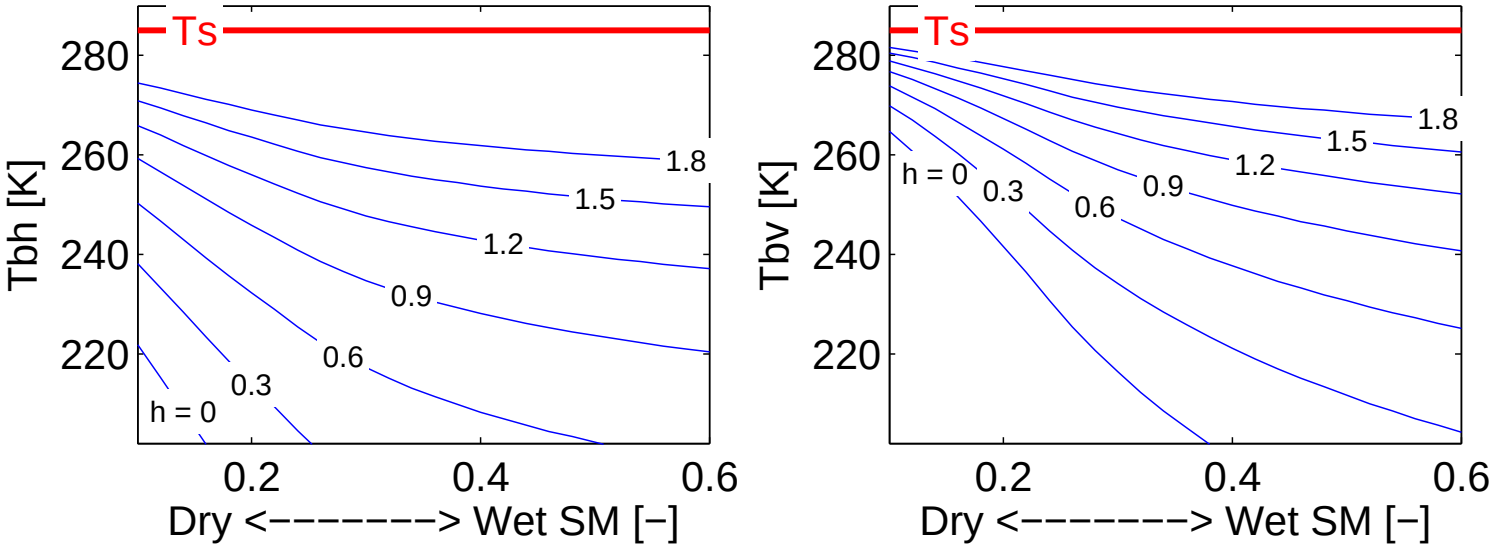


- measured by passive microwave sensors
- dry and warm land surface → high Tb [K]
- wet and cold land surface → low Tb [K]

The relationship between brightness temperature (Tb) and soil moisture (SM) is very sensitive to local parameters



Tau-Omega Radiative Transfer Model (RTM)

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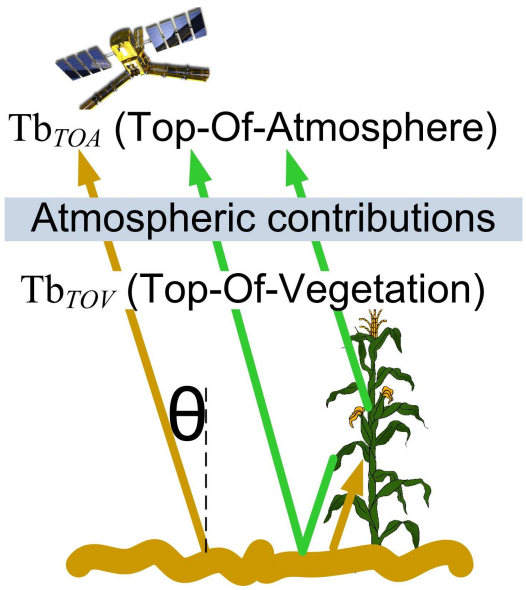
Zero-order microwave radiative transfer model:



- **soil contributions**: moisture (dielectric constant), roughness (h) $\rightarrow$ rough reflectivity (r_p)
- **vegetation contributions**: opacity (τ_p) $\rightarrow$ attentuation (A_p); scattering (ω)
- **atmospheric contributions**

$$
\begin{aligned}
\mathrm{Tb}_{TOA,p} &= \mathrm{Tb}_{au,p} + \exp(-\tau_{atm,p})\mathrm{Tb}_{TOV,p} \\
\mathrm{Tb}_{TOV,p} &= \mathrm{T}_s(1-r_p)A_p \\
&\quad + \mathrm{T}_c(1-\omega_p)(1-A_p)(1+r_pA_p) \\
&\quad + \mathrm{Tb}_{ad,p}r_p{A_p}^2
\end{aligned}
$$

GEOS-5 Catchment LSM (Fortuna 2.3; 5 cm surface layer):

- soil moisture, surface temperature ($\mathrm{T}_s = \mathrm{T}_c$), LAI,...

SMOS and SMAP

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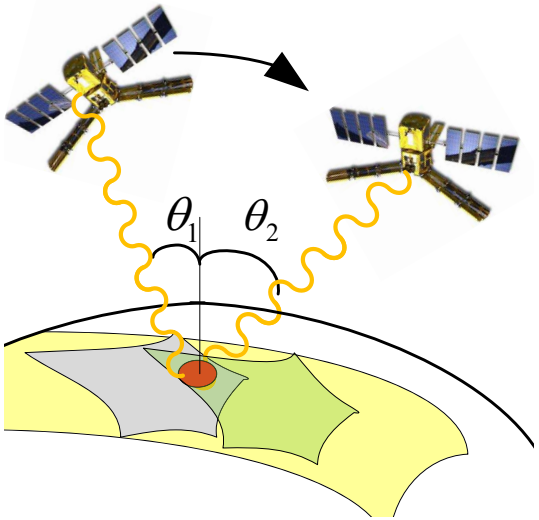
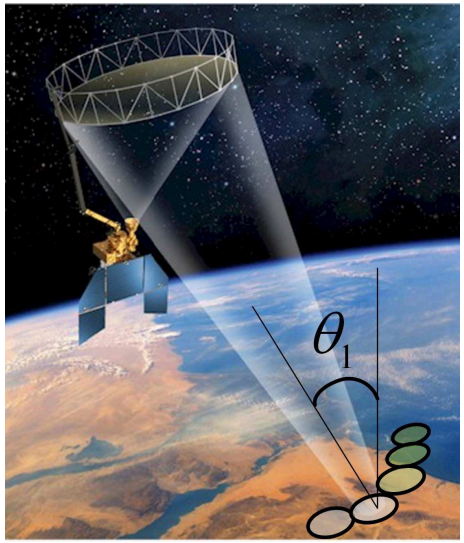
SMOS (ESA, Soil Moisture Ocean Salinity)



- launched November 2009
- L-band radiometer
- sensing depth = 5 cm
- 40 km resolution

SMAP (NASA, Soil Moisture Active Passive)



- launch 2014
- L-band radiometer/radar
- sensing depth = 5 cm
- 3-40 km resolution

→ Calibrate radiative transfer model using Tb data from SMOS to prepare for SMAP

SMOS and SMAP

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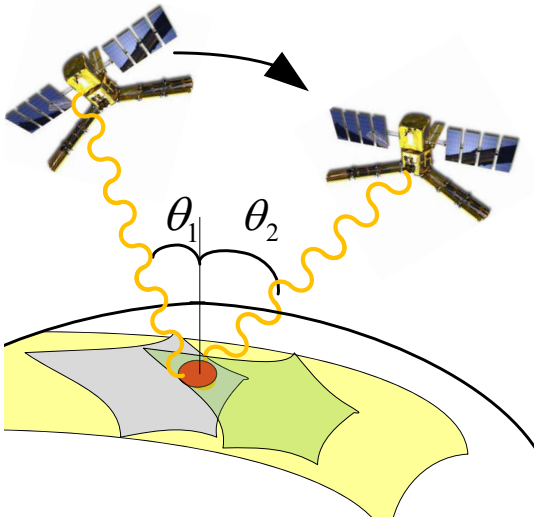

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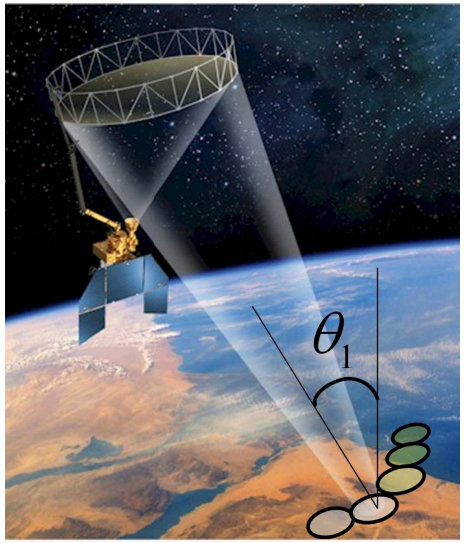
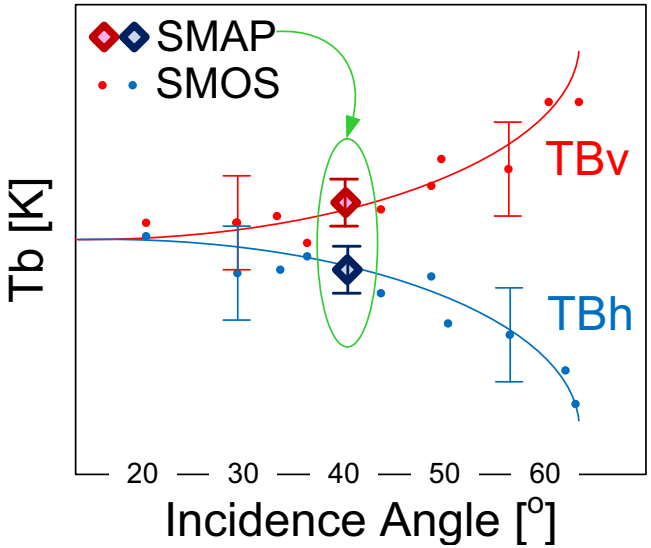


Each location seen with multiple incidence angles per overpass

Each snapshot:

$\sigma \sim 4$ K



Each location seen once per overpass at fixed 40° incidence angle (conical scan)

$\sigma \sim 1.3$ K

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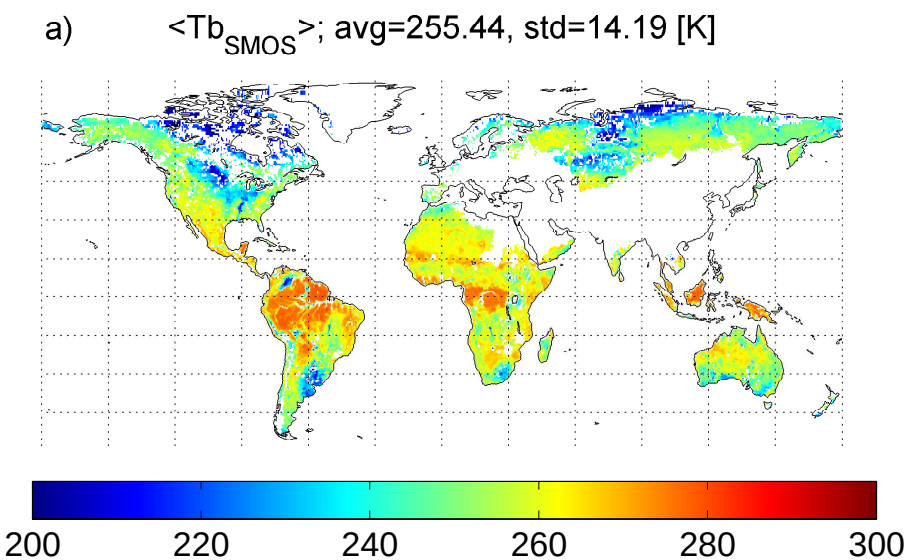
Calibration

Before Calibration

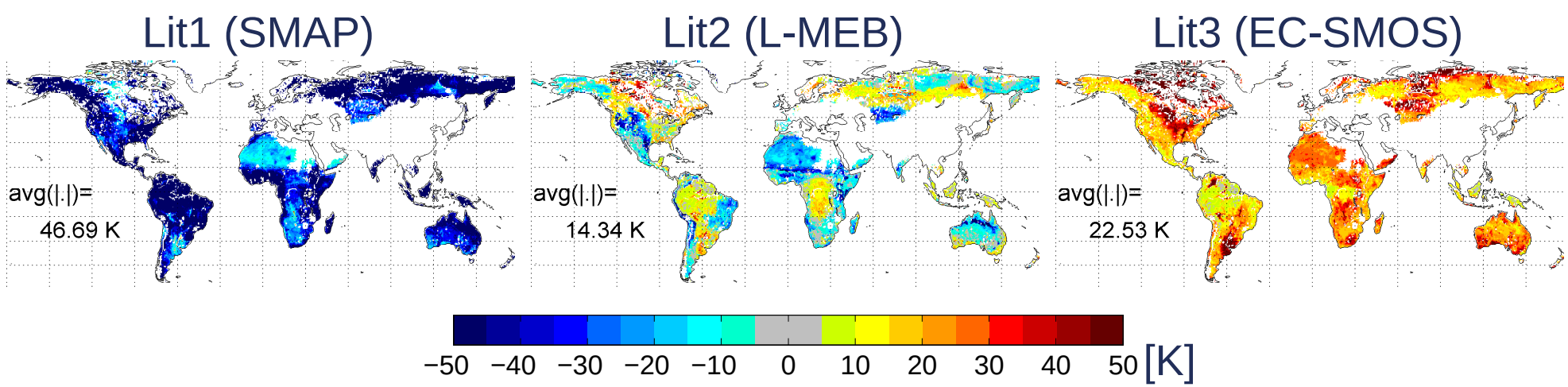
Large time-mean bias



1 Jan 2011 - 1 Jan 2012, 36 km

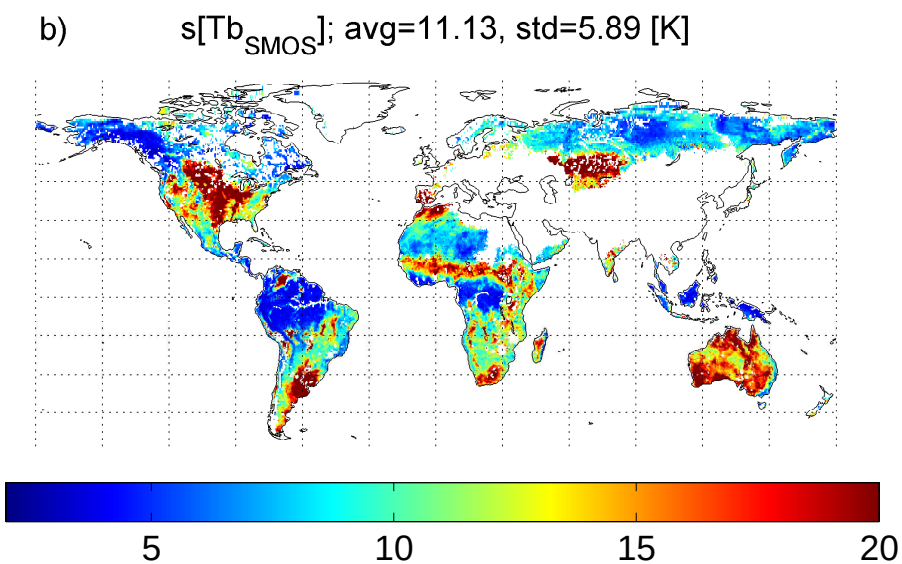
⇐ **SMOS observed** Tb, H-pol, 42.5^{o}

⇓ **Model-minus-Observations**, with the model using prescribed RTM parameters (SMAP, L-MEB literature, ECMWF-SMOS)



Before Calibration

Large differences in temporal variability



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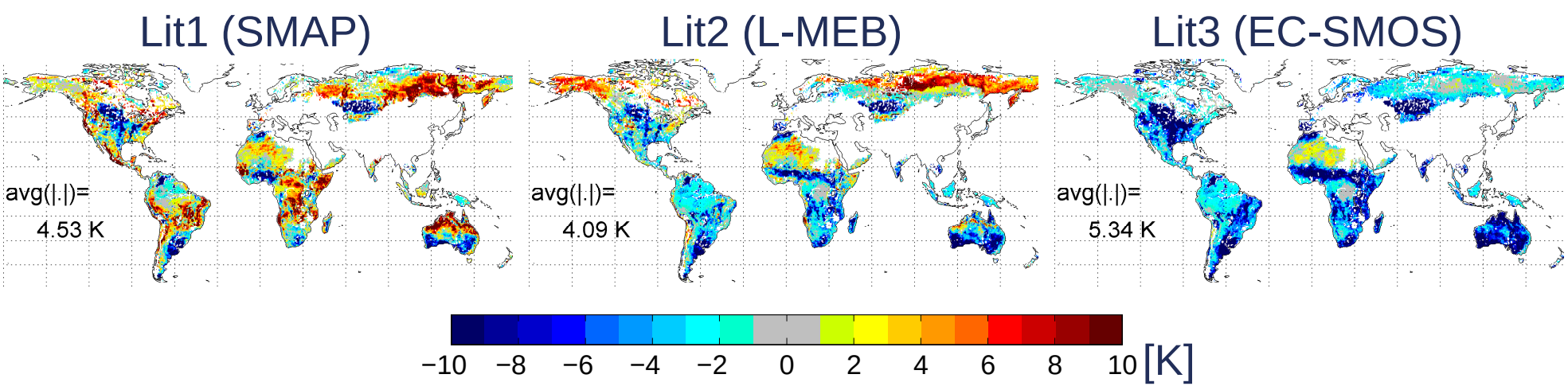

SMOS versus CLSM/RTM

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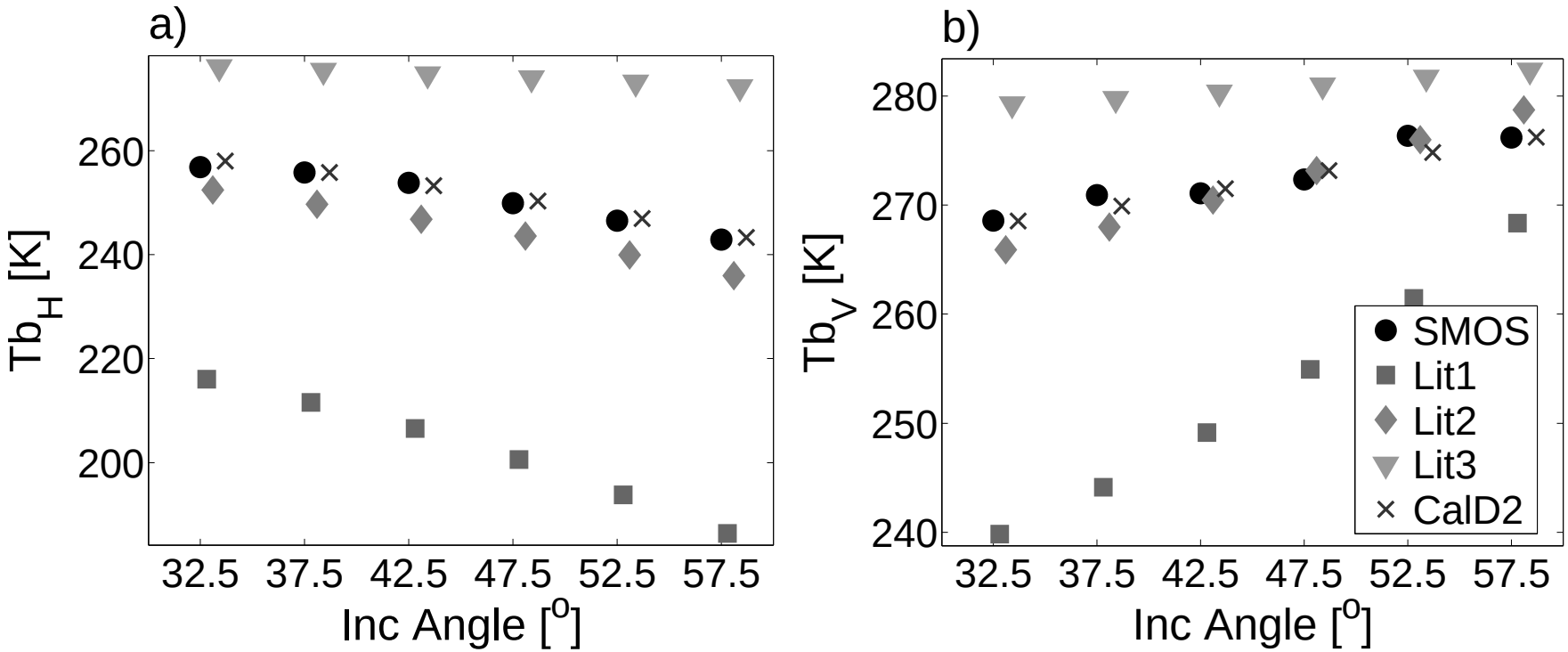
Ascending multi-angular Tb, annual (2011) global average



- bias is angle- and polarization-dependent
- after calibration with 2010 data, CLSM/RTM Tb will be unbiased vs. SMOS in 2011

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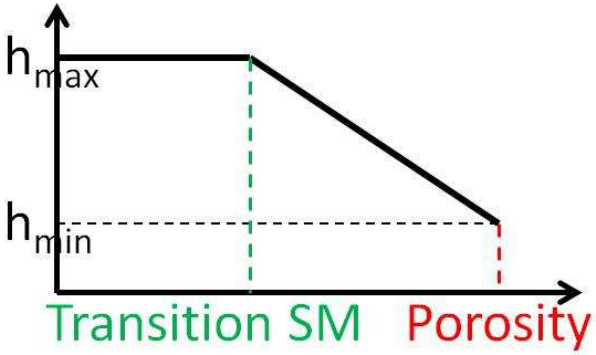
Different calibration scenarios:

1) Selected parameters $\alpha(N_\alpha)$, control vector:

Parameter	[min, max]	A	B	C	D
h_{min}	[0, 2.0]	X	X	X	X
$\Delta h \equiv h_{max} - h_{min}$	[0, 1.0]	X	X	X	X
ω	[0, 0.3]		X		X
b_H	[0, 0.7]			X	X
$\Delta b \equiv b_V - b_H$	[-0.15, 0.15]			X	X

- microwave roughness h
- scattering albedo ω
- vegetation opacity τ $= b_p \; LEWT \; LAI$



2) Prior information $\alpha_0(N_\alpha)$:

bounded Gaussian, centralized around Lit1, Lit2, Lit3

$\Rightarrow$ total of 12 calibration scenarios (e.g. CalD2)

Multi-Variate Objective Function J

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For 6 angles, 2 polarizations, 2 orbit directions ($\sum_\theta \sum_p \sum_d$), penalize

- differences in long-term mean
- differences in long-term standard deviation
- deviations from prior (literature) parameter values

Search algorithm: particle swarm optimization; 1 year (2010)

$$J = W_m \sum_\theta \sum_p^{H,V} \sum_d^{A,D} \frac{N_{\theta,p,d}}{N} \frac{(< \mathrm{Tb}_o > - < \mathrm{Tb}(\alpha) >)^2_{\theta,p,d}}{\sigma_m^2} \Bigg\} J_{<.>,o}$$

$$+ W_s \sum_\theta \sum_p^{H,V} \sum_d^{A,D} \frac{N_{\theta,p,d}}{N} \frac{(s[\mathrm{Tb}_o] - s[\mathrm{Tb}(\alpha)])^2_{\theta,p,d}}{\sigma_s^2} \Bigg\} J_{s[.],o}$$

$$+ W_\alpha \frac{1}{N_\alpha} \sum_{i=1}^{N_\alpha} \frac{(\alpha_{0,i} - \alpha_i)^2}{\sigma^2_{\alpha_{0,i}}} \Bigg\} J_\alpha$$

N_α parameters simultaneously optimized at each gridcell individually

Globally Averaged J

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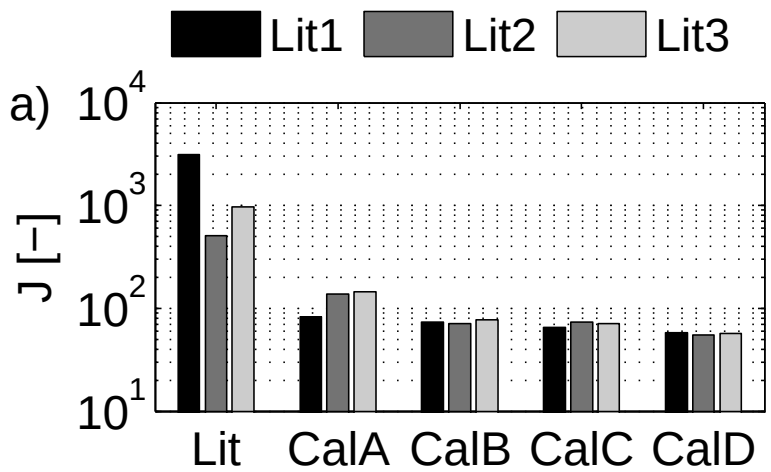

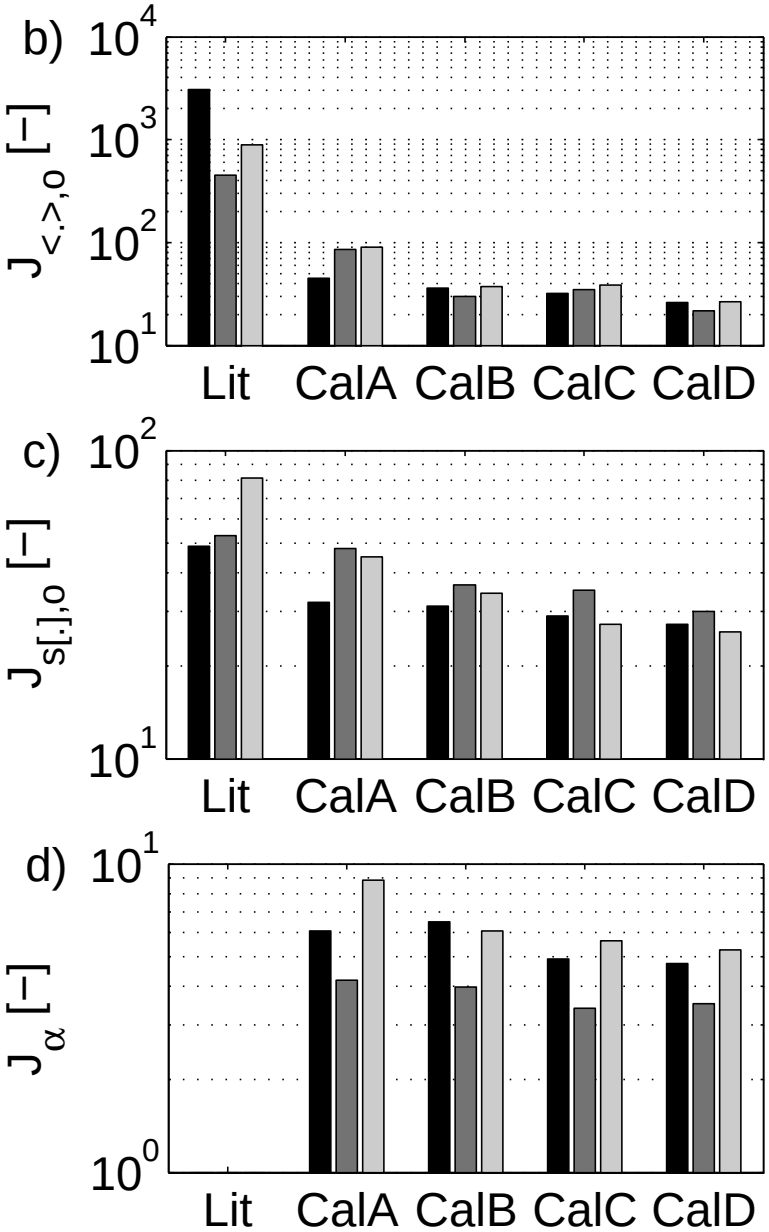

- $\Uparrow$ J is reduced after calibration
- $\Uparrow$ CalA (only calibrating h) is clearly not optimal
- $\Rightarrow$ mean bias ($J_{<.>,o}$) is the largest component, and most reduced through calibration
- $\Rightarrow$ standard deviation difference ($J_{s[.],o}$) optimized, but strongly constrained by LSM variations

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Brightness Temperatures

CLSM/RTM minus SMOS Tb - Mean

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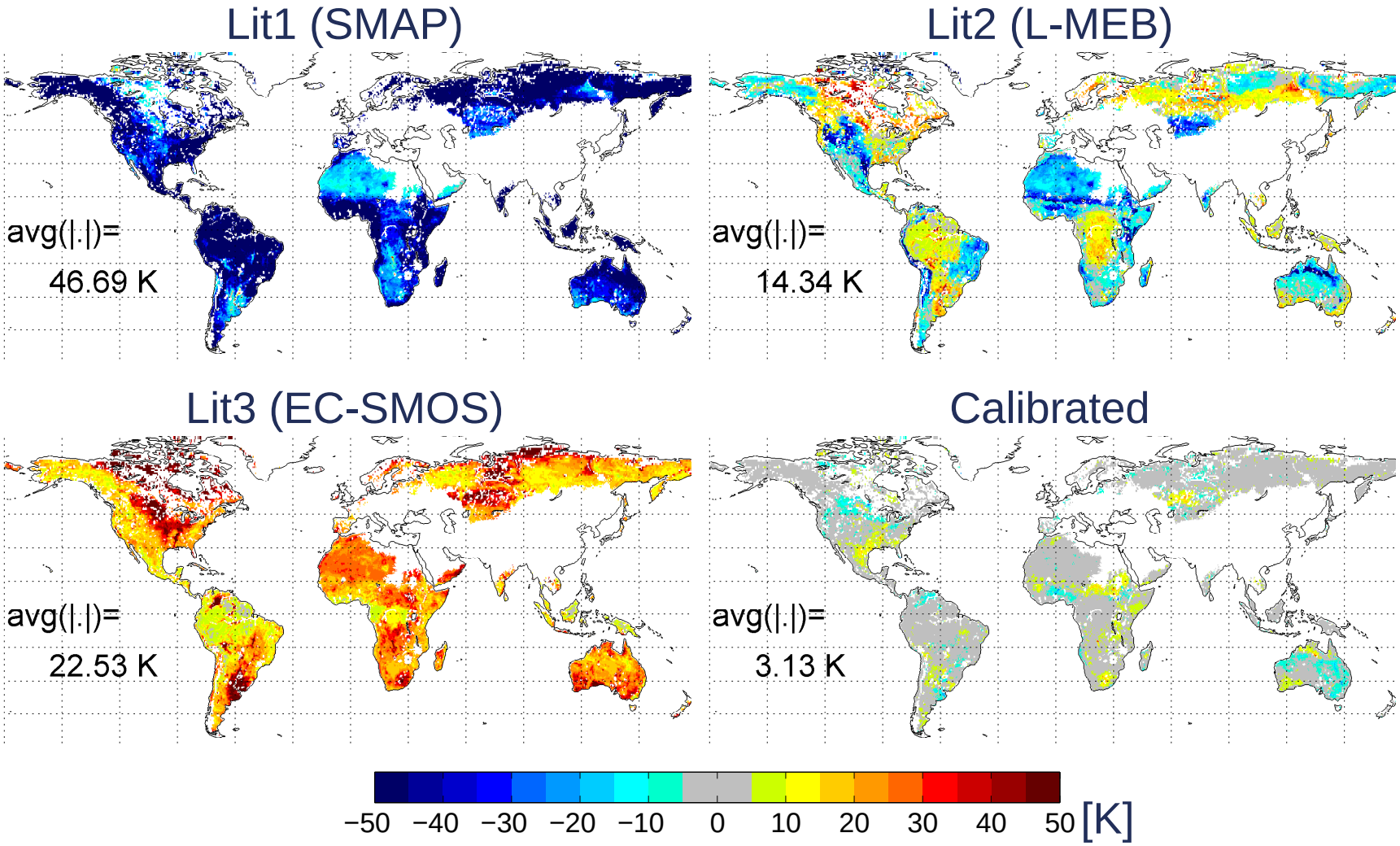
H-pol, 42.5^{o}, ascending, 1/1/2011-1/1/2012 (validation period)



- mostly unbiased long-term mean in the period *after* calibration
- bias independent of incidence angle and pol (not shown)

CLSM/RTM minus SMOS Tb - Standard Deviation

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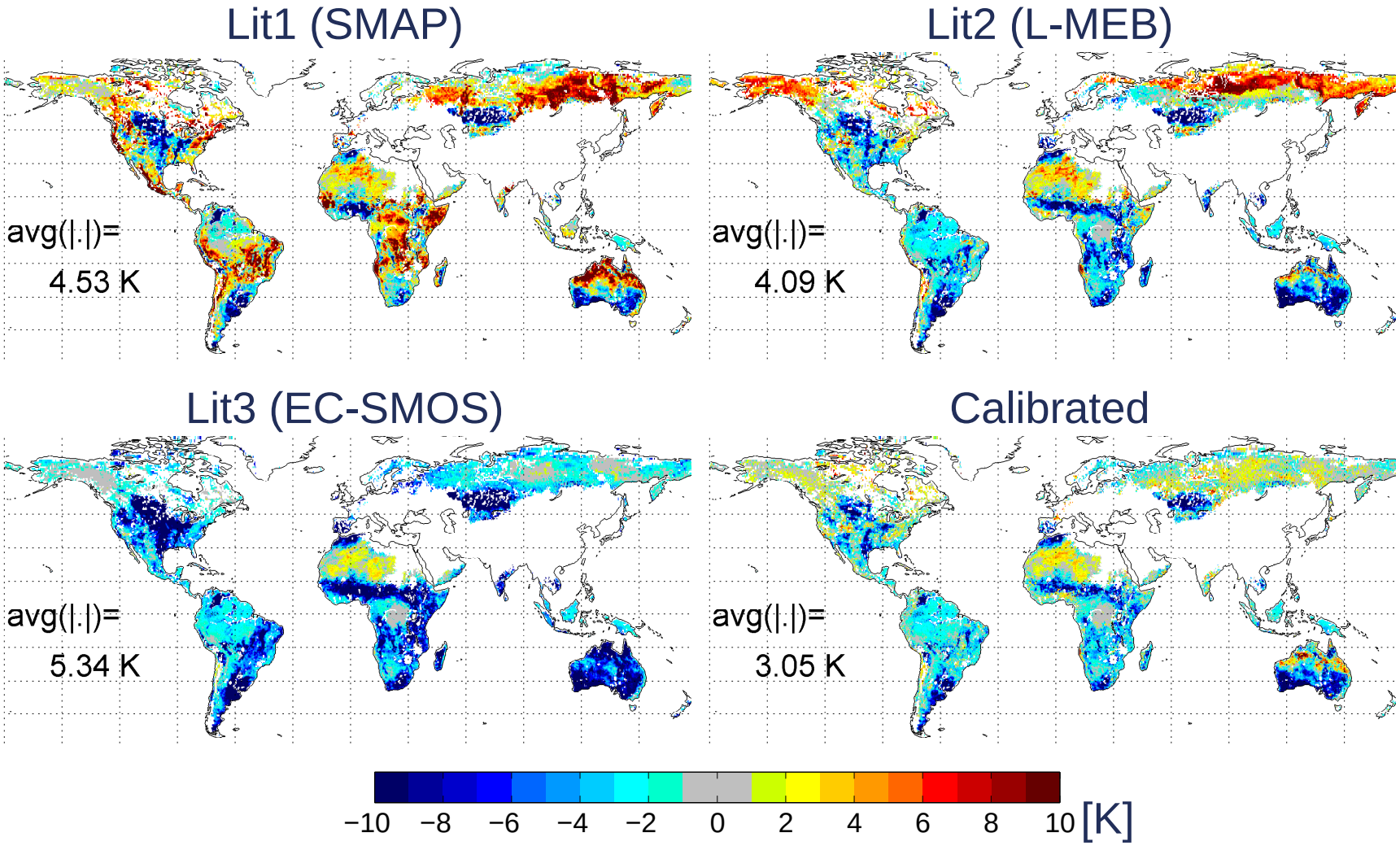
H-pol, 42.5^o, ascending, 1/1/2011-1/1/2012 (validation period)



- preserved temporal variability, while reducing the bias

Sensitivity of $Tb_H(42.5^o)$ to Soil Moisture

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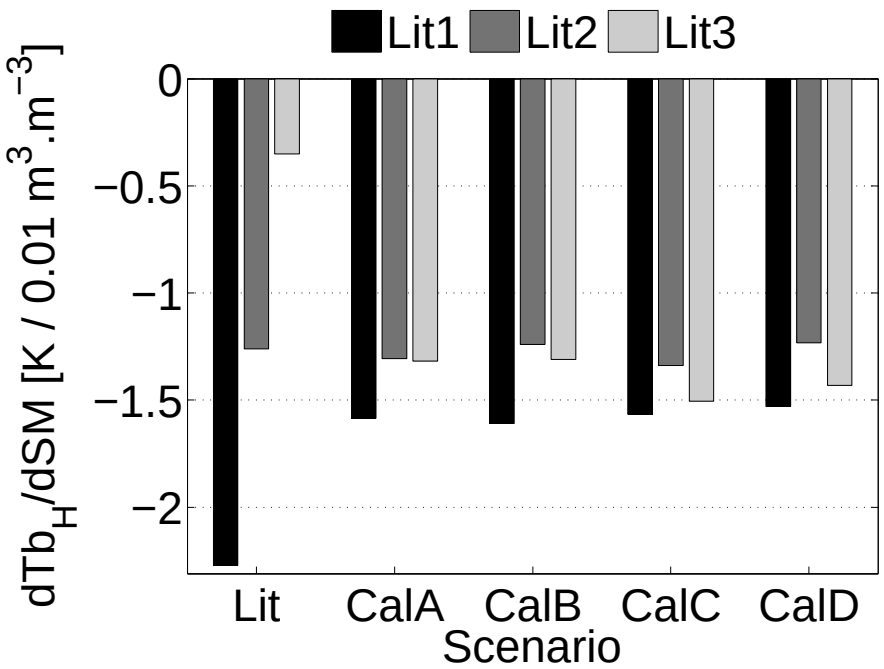

- rule of thumb for bare soil:
  dSM $\sim$ 0.01 $m^3.m^{-3}$ corresponds to $dTb_H(40^o) \sim$ 2-3 K
- Lit3 clearly lacks sensitivity, because of a too high h-parameter
- after calibration, the sensitivity is reasonable and closest to Lit2, regardless of prior values

$\rightarrow$ Important for assimilation: a difference between observed and simulated Tb will be mapped to a change in soil moisture

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Global Averages

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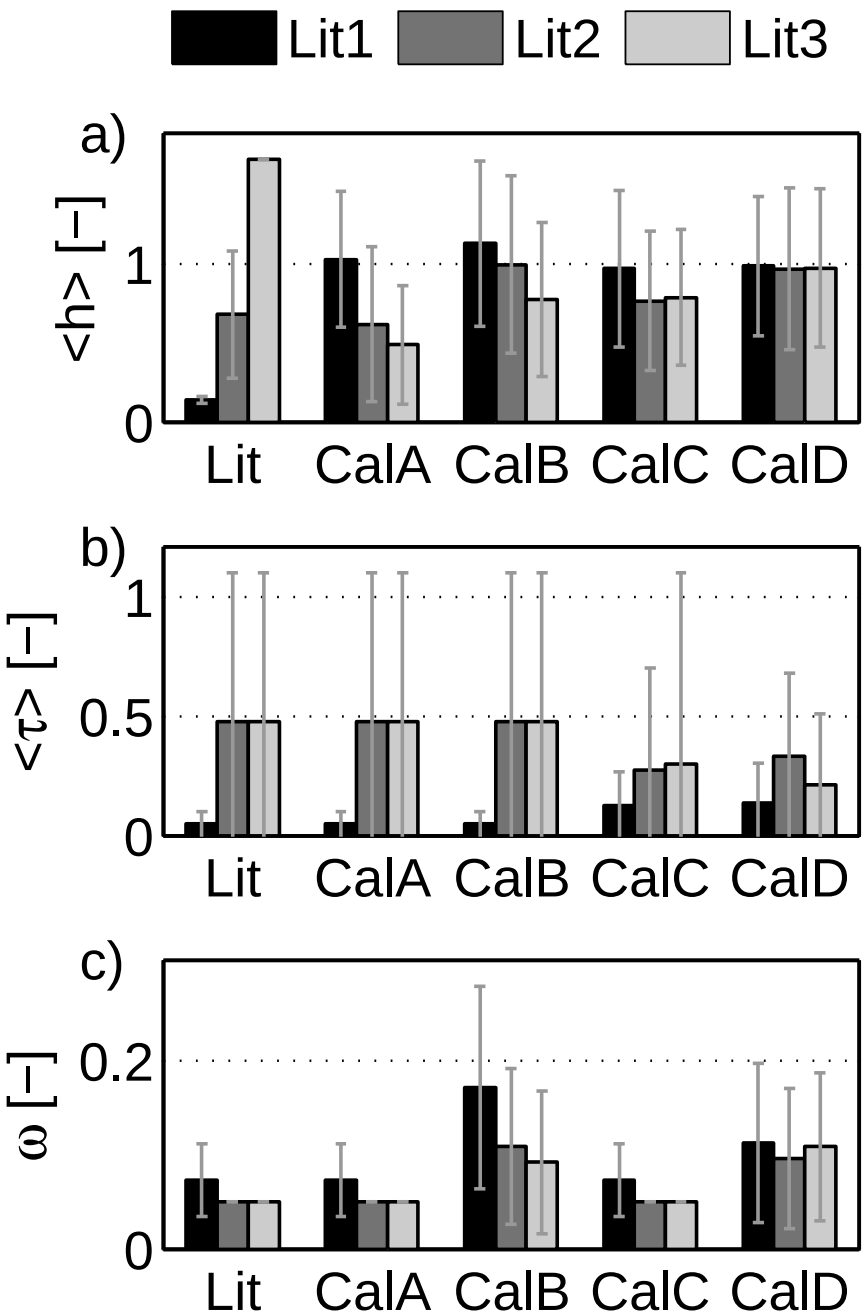
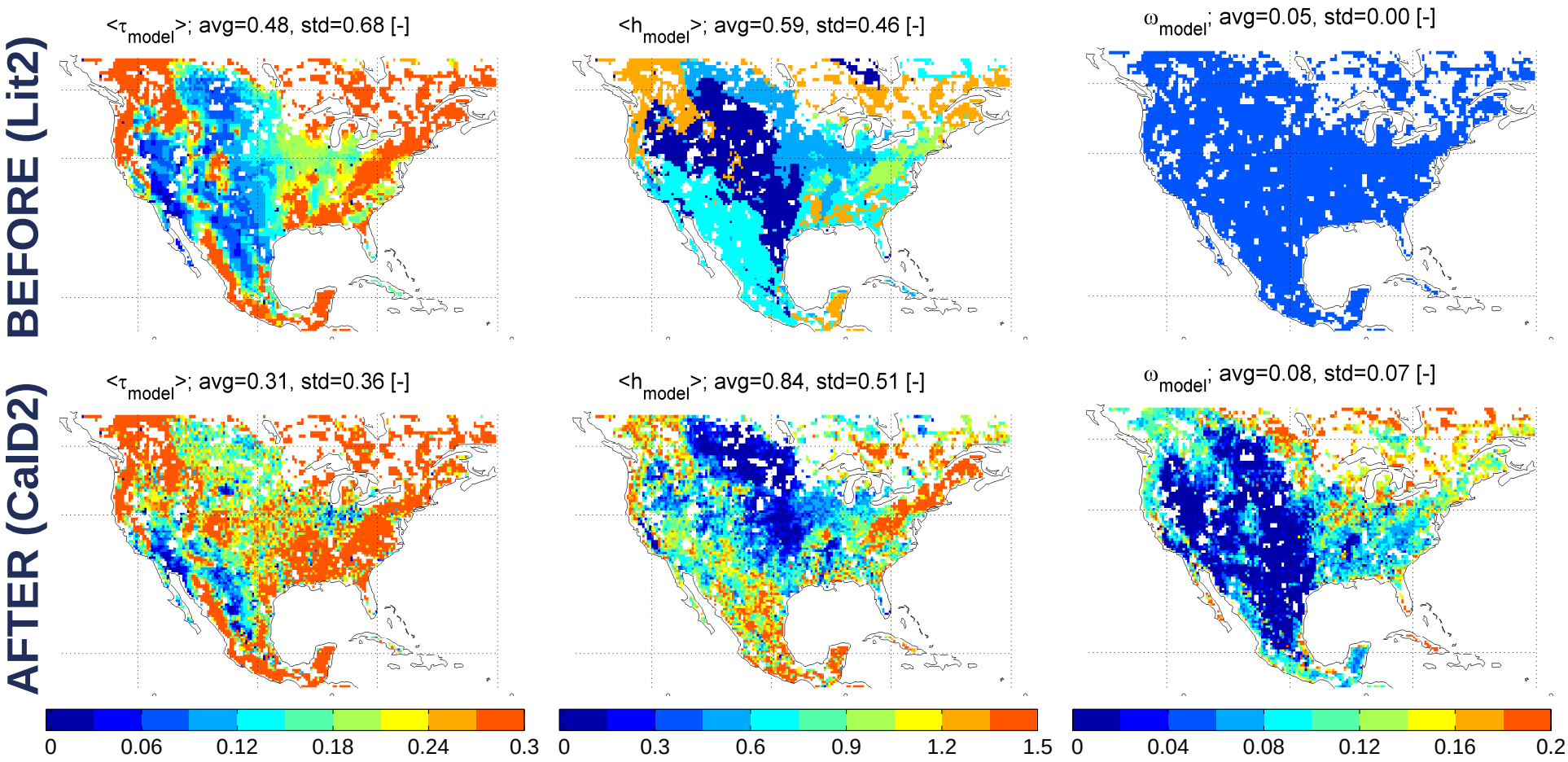


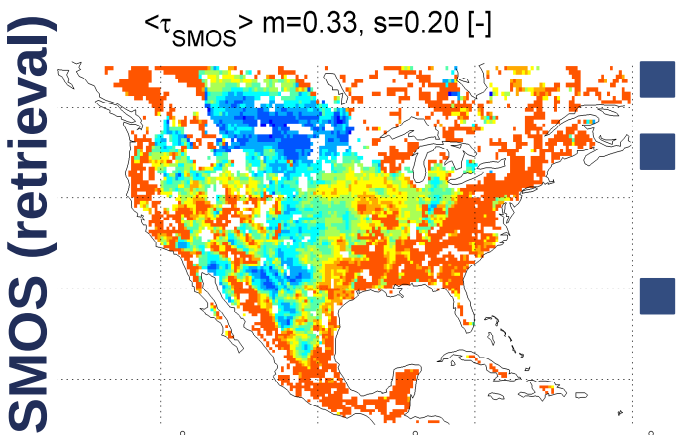
Parameter estimates are more consistent for the most complex calibration scenario.

Param	A	B	C	D
h_{min}	X	X	X	X
Δh	X	X	X	X
ω		X		X
b_H			X	X
Δb			X	X

- $< h >$ = time-averaged (soil moisture dependent)
- $< \tau >$ = time-averaged (LAI dependent), polarization-averaged
- ω = constant

Spatial Patterns: $< \tau >, < h >, \omega$





- from homogeneous to locally optimized parameters
- vegetation/soil/climate patterns
  (need RTM recalibration with new CLSM parameters)
- calibrated and SMOS τ have a similar magnitude

Spatial R: $< \tau >, < h >, \omega$

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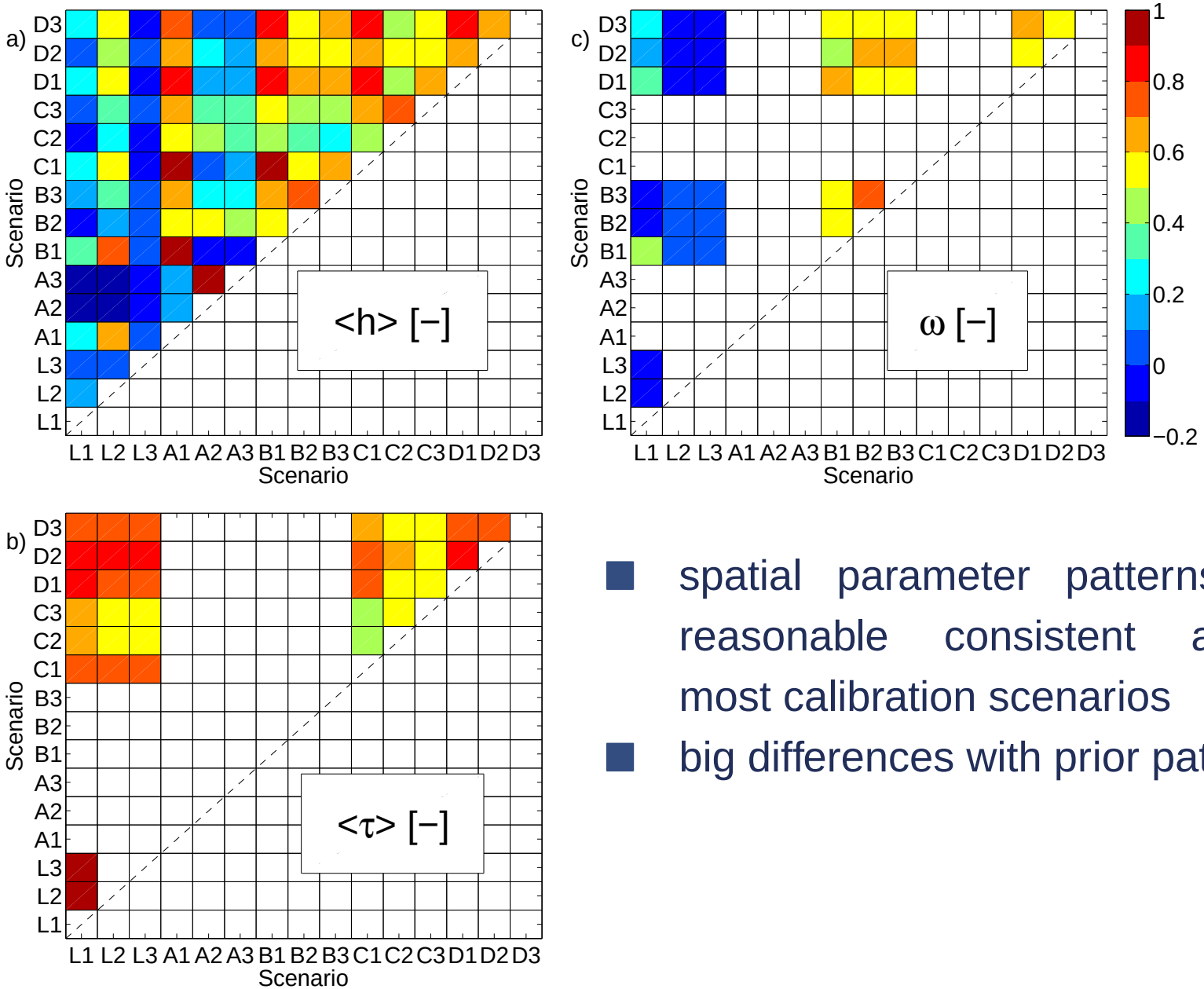
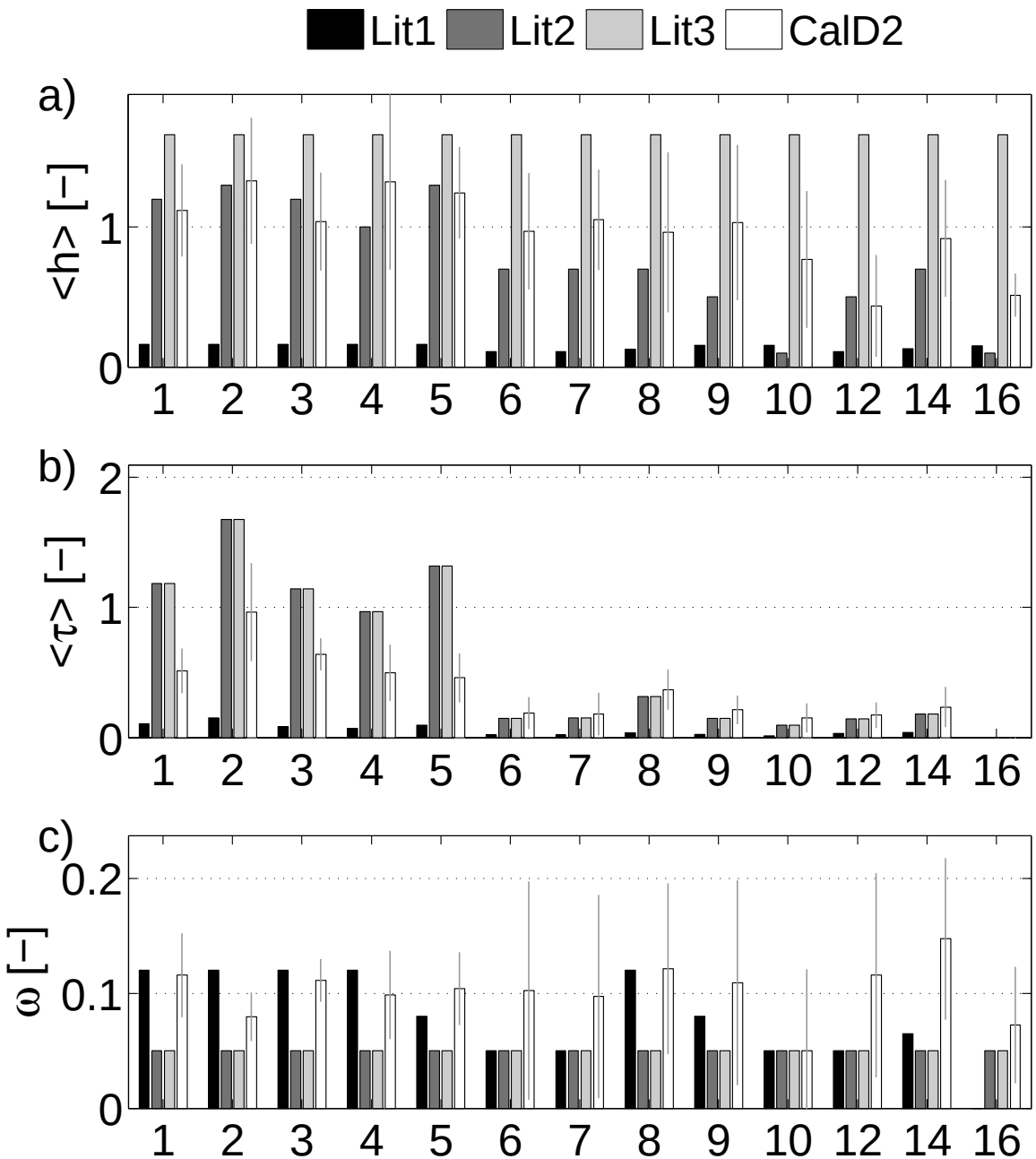


- spatial parameter patterns are reasonable consistent across most calibration scenarios
- big differences with prior patterns

Optimal $< \tau >$, $< h >$, ω



	IGBP land cover
1	Evergreen Needleleaf Forest
2	Evergreen Broadleaf Forest
3	Deciduous Needleleaf Forest
4	Deciduous Broadleaf Forest
5	Mixed Forest
6	Closed Shrublands
7	Open Shrublands
8	Woody Savannas
9	Savannas
10	Grasslands
12	Croplands
14	Crop and Natural Vegetation
16	Barren or Sparsely Vegetated

- CalD2 = Lit2 as prior, calibrate h_{min}, h_{max}, b_H, b_V, ω
- reasonable optimal parameters; large within-class variability
- when using class-averaged (as opposed to local) calibrated parameters, the RTM still performs better than with Lit1, Lit2 or Lit3

$\rightarrow$ use aggregate CalD2 parameters in unobserved regions

Vegetation Opacity τ

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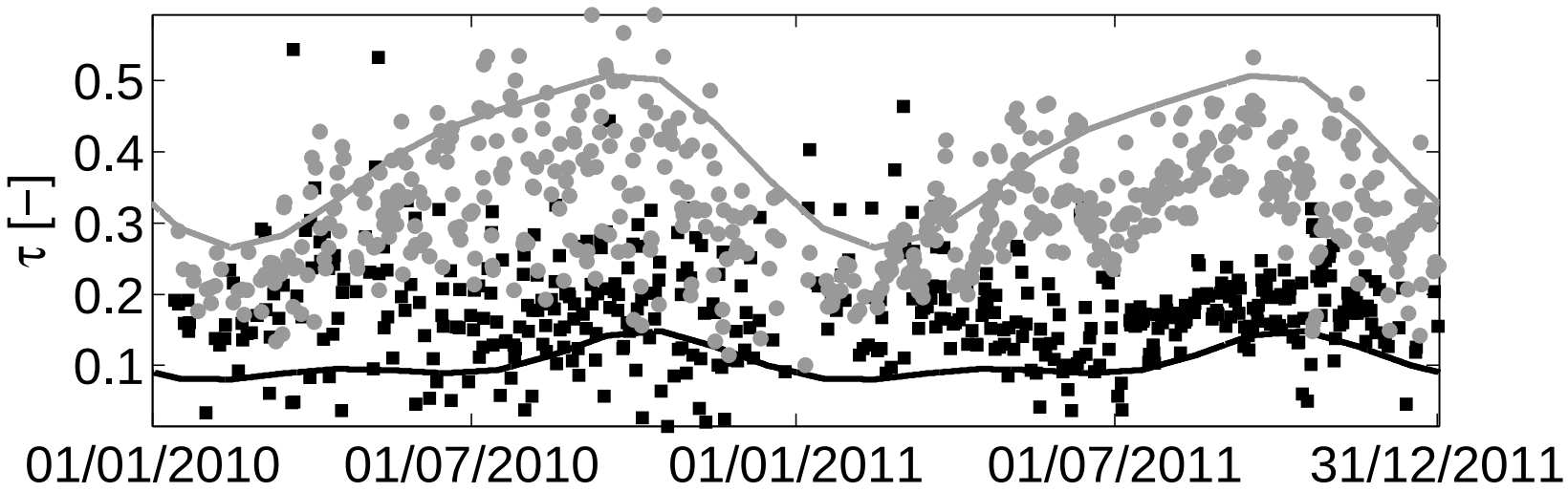

- Little River, Georgia (● SMOS retrievals; – CLSM/RTM)
- Walnut Gulch, Arizona (■ SMOS retrievals; – CLSM/RTM)

⇒ Vegetation opacity values from the calibrated CLSM/RTM distiguish well between more and less vegetated areas, and are consistent with SMOS retrievals

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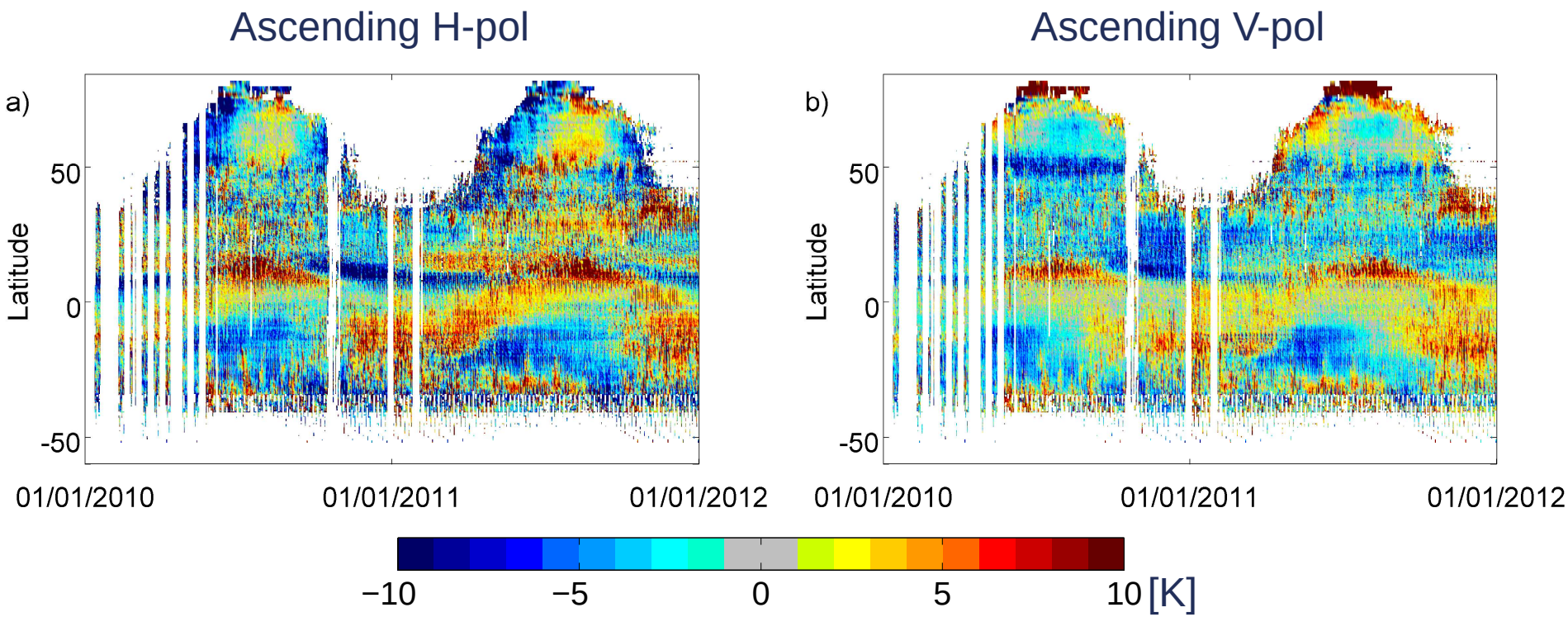
Hovmöller Plots: CLSM/RTM minus SMOS Tb



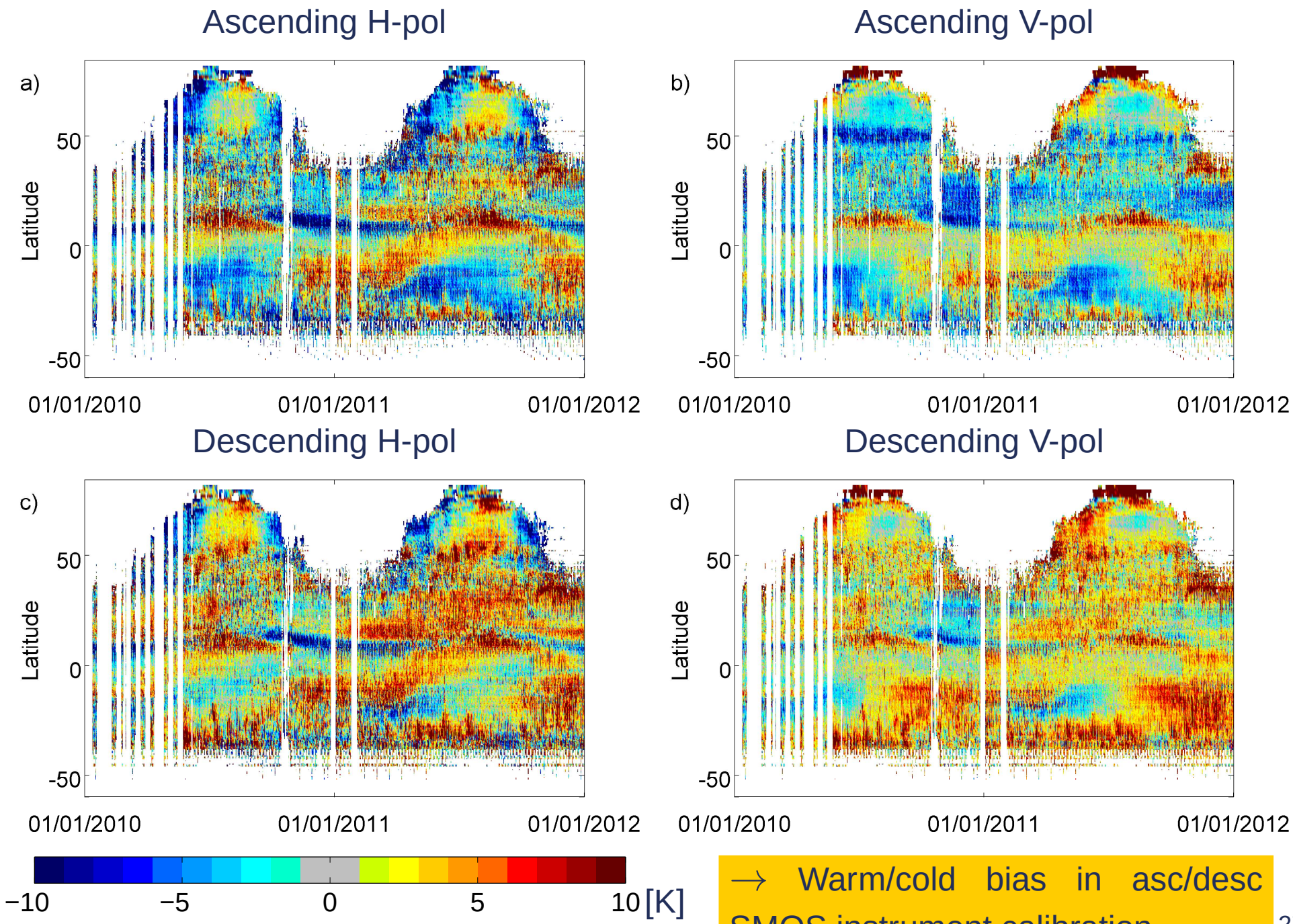
- 6-angle average (32.5, . . . , 57.5)^o
- using full-pol SMOS data only (early 2010: switch dual-full pol)

Clear seasonal biases remaining,
partly due to CLSM/RTM Tb biases, partly due to SMOS Tb biases

For example: ascending V-pol in North America:

- simulated Tb_V cannot exceed CLSM T_s, irrespective of the parameters
- ascending SMOS sees military radar, remaining RFI contamination may be present

Hovmöller Plots: CLSM/RTM minus SMOS Tb



→ Warm/cold bias in asc/desc SMOS instrument calibration

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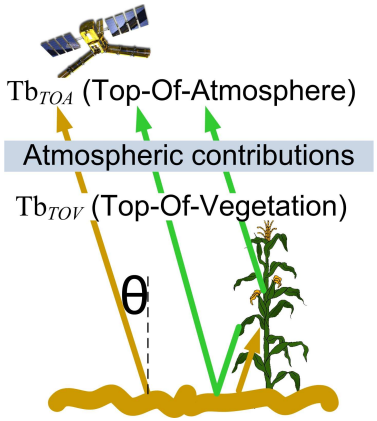
- Biases between SMOS and CLSM/RTM Tb, when using literature parameters
- **RTM calibration/validation (split sample 2010 / 2011)**
  - multi-angular; multi-polarization; multi-orbit; local
  - objective function: minimize
    - differences in long-term mean;
    - differences in long-term standard deviation;
    - deviations from prior (literature) parameter values.
  - long-term unbiased Tb, seasonal to diurnal biases remaining
  - realistic **effective** RTM-parameter patterns
- **Future**
  - new CLSM climatology will need new calibration
  - Tb assimilation, SMAP L4_SM product